Modeling Protocol
for
Regional Haze Reasonable Progress Goals
in North Dakota

(Final)

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North Dakota Department of Health
Division of Air Quality
918 E. Divide Avenue
Bismarck, ND 58501

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1 Introduction

The EPA Regional Haze Rule[1] (Rule) specifies that modeling must be conducted to demonstrate reasonable progress toward the goal of achieving natural visibility in each PSD Class I area. The Rule also specifies that natural visibility conditions should be achieved by 2064. The uniform rate of progress defines the visibility improvement that would be needed each year, starting with the base period of 2000-2004, to achieve natural visibility conditions in 2064 in each Class I area. This progression is illustrated in Figure 1-1. To track visibility improvement, the Rule specifies several milestone dates for meeting intermediate reasonable progress goals, that the State must establish, the first of which is the 2018 goal, for each Class I area. The uniform rate of progress for 2018 is determined by interpolating from the uniform rate of progress path, as illustrated in Figure 1-1. This protocol will assume that the 2018 goal for each Class I area is the glide path (uniform rate of progress), but the reasonable progress goal established by the State for 2018 for each Class I area may or may not be equal to the uniform rate of progress for 2018.

To demonstrate reasonable progress with respect to the 2018 visibility goals, the Rule specifies that visibility on the 20% worst days must improve enough to meet the goal, while visibility on the 20% best days must not deteriorate, between the base period (2000-2004) and 2018. Air quality modeling will be used to project future visibility, accounting for proposed BART controls and other visibility-affecting emissions increases/decreases. Modeling will be used in a relative sense. Baseline and projected future emission inventories will be modeled to develop a future/baseline prediction ratio (relative response factor). The ratio will then be applied to baseline monitoring data for visibility-affecting species to project future visibility.

The Western Regional Air Partnership (WRAP) regional planning organization has established a Regional Modeling Center (RMC) to assist member States, including North Dakota, with modeling to determine status with respect to the 2018 goals. The RMC is applying a chemically sophisticated grid model (CMAQ), on a regional basis, to project future visibility in Class I areas in the WRAP region[2]. The RMC has developed comprehensive base period and future period visibility-affecting emission inventories to use with CMAQ, and has performed numerous studies using base period model and monitoring data to evaluate CMAQ performance[3].

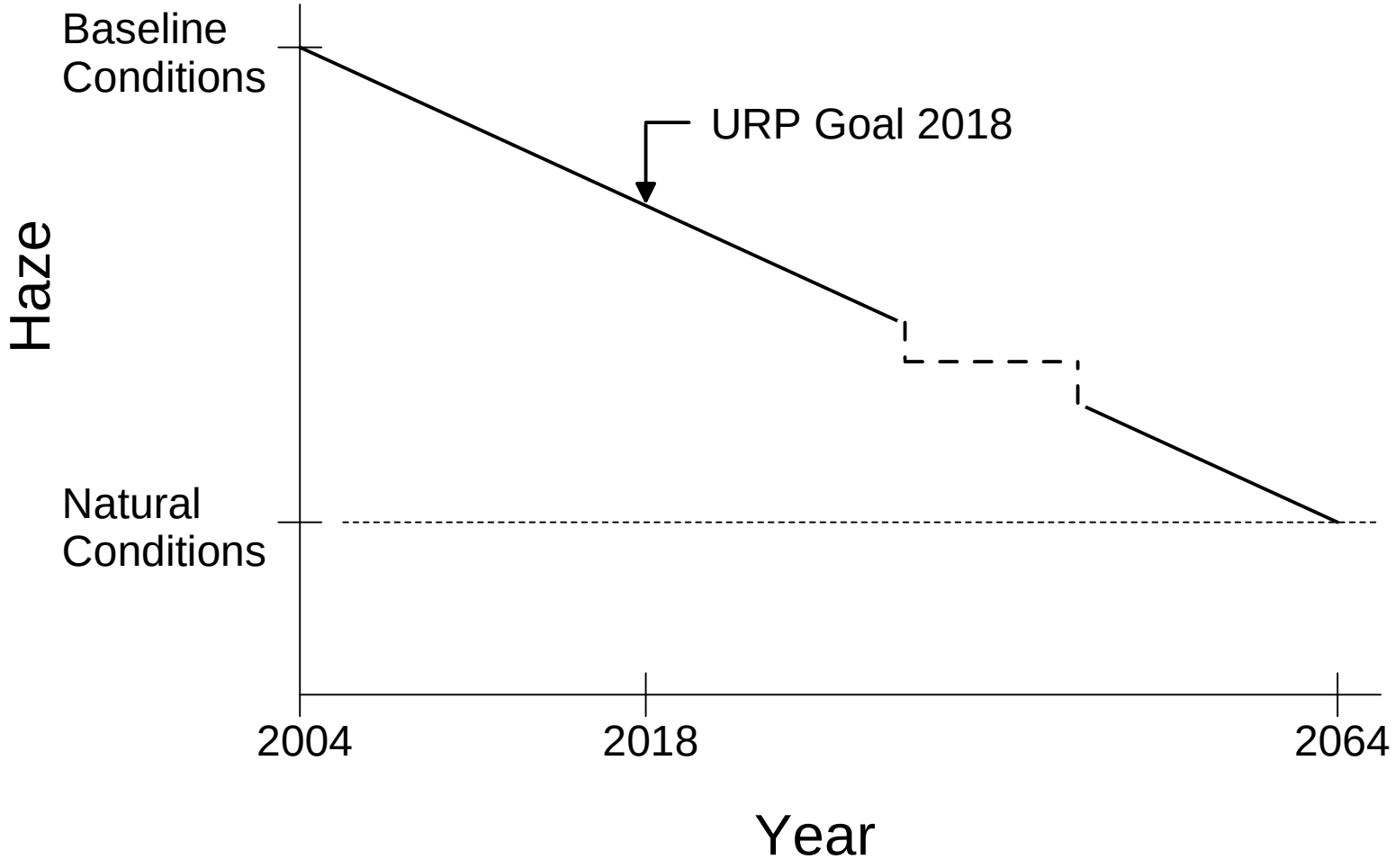
Though the North Dakota Department of Health (NDDoH) intends to incorporate much of the WRAP RMC work in its own analysis of visibility goals in North Dakota Class I areas, the NDDoH recognized it would have to develop its own modeling capability for visibility projection

[1] 40 CFR 51.308

[2] Tonnesen et. al., Morris, Adelman, 2006. 2006 Report for the Western Regional Air Partnership (WRAP) Regional Modeling Center (RMC). Western Regional Air Partnership, Denver, CO 80202.

[3] See WRAP RMC web site at http://pah.cert.ucr.edu/aqm/308/

Figure 1-1
Regional Haze Uniform Rate of Progress



in order to address weight of evidence issues not included in WRAP modeling, such as discounting the impact of international sources. Further, the NDDoH had concerns regarding the resolution of the WRAP CMAQ simulations, particularly for large point sources.

The RMC is applying CMAQ on a National basis using a grid resolution of 36 km, with no plume-in-grid treatment. This means that emissions from point sources are immediately mixed uniformly throughout a 36 km (square) grid cell volume, which may overstate the dilution of the plume, and the speed of chemical reactions for species contained in the plume, especially for sources located relatively near Class I areas. Consequently, the contribution of visibility-affecting species from these sources may be misrepresented for both base period and future period modeling. This limitation in treatment of point sources is recognized in CMAQ documentation[4].

To provide a local modeling capability, the NDDoH proposes a hybrid modeling approach for determining status with respect to the visibility goals. This approach involves nesting the local NDDoH CALPUFF domain within the WRAP National CMAQ domain, and applying the Lagrangian CALPUFF model in a retrospective sense to more realistically define plume geometry for local point sources. To implement the nesting, hourly output concentrations from WRAP CMAQ will be used to set hourly boundary conditions for CALPUFF. The use of CMAQ output to set CALPUFF boundary conditions has been suggested by Escoffier-Czaja and Scire[5]. Location of the NDDoH CALPUFF domain within the National CMAQ domain is illustrated in Figure 1-2.

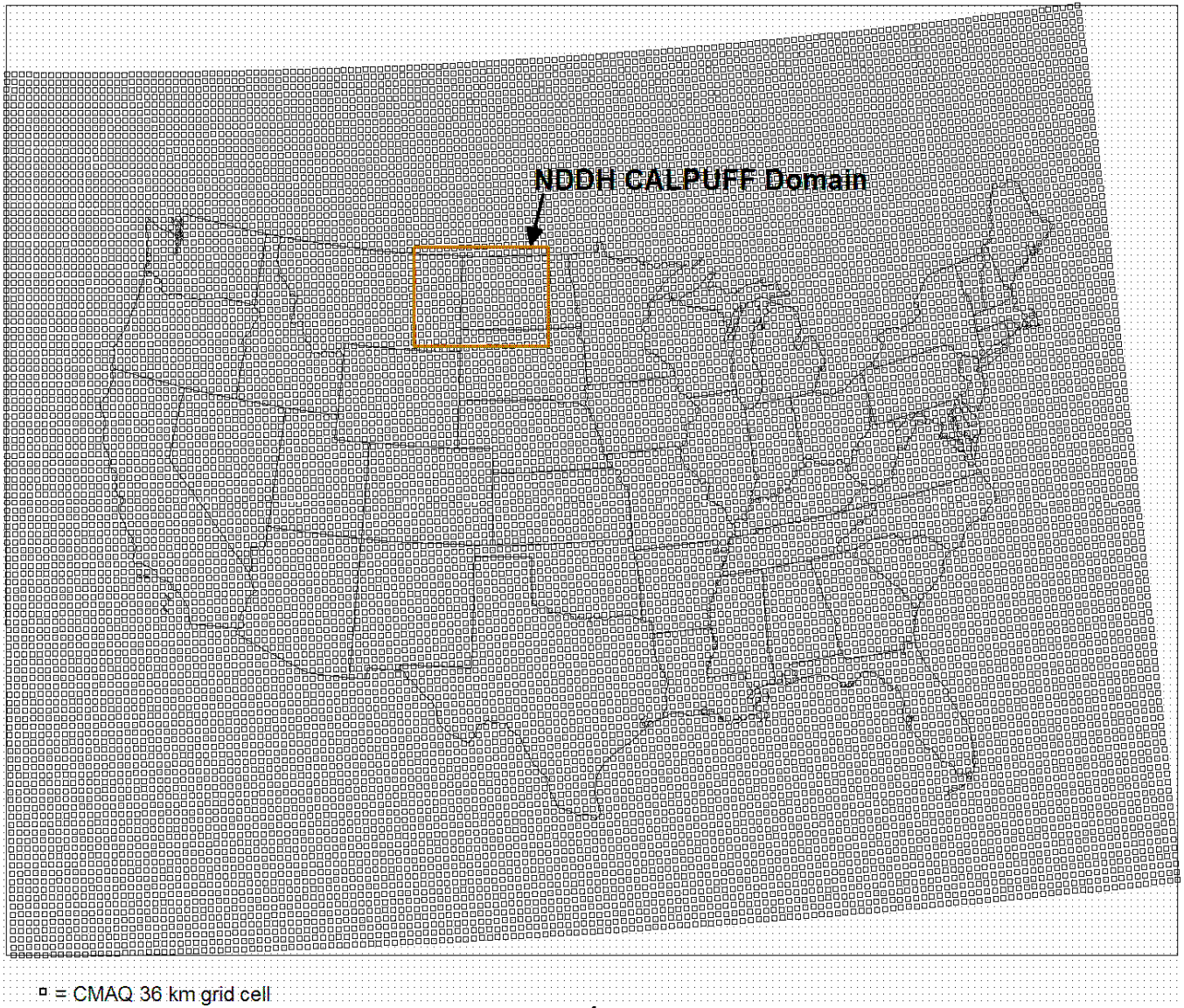
CALPUFF nesting will be used for simulation of SO_2-SO_4-NO_X-HNO_3-NO_3 chemistry and transport, and thus sulfate and nitrate predictions, only. Results for all other visibility-affecting species, including organic carbon mass, elemental carbon, fine particulate, and coarse particulate, will be obtained directly from the CMAQ output for the grid cell containing the subject Class I area IMPROVE monitor. CMAQ output will be combined with CALPUFF results for sulfate and nitrate in order to perform necessary light extinction calculations. In this way, the NDDoH will take advantage of the sophistication of the RMC approach for other particulate components, which reflect a very small percentage of emissions from the local point sources of concern.

The NDDoH protocol for modeling visibility progress goals will generally adhere to EPA *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality*

[4] EPA, 1999. Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Office of Research and Development, Washington DC 20460.

[5] Escoffier-Czaja and Scire, 2005. Comments on the Computation of Nitrate Using the Ammonia Limiting Method in CALPUFF. Appendix A, Draft Protocol for the Application of the CALPUFF Model for Analyses of Best Available Retrofit Technology (BART), VISTAS.

Figure 1-2
WRAP CMAQ Domain and NDDoH CALPUFF Domain



Goals for Ozone, $PM_{2.5}$, and Regional Haze[6]. An evaluation of performance for the CMAQ-CALPUFF hybrid modeling system will be conducted first. Then baseline (2000-2004) and future (2018) emission scenarios will be modeled, using the hybrid modeling system, in order to develop relative response factors (RRF's). Finally, RRF's will be applied to baseline IMPROVE monitoring data to project future visibility in North Dakota Class I areas. These Class I areas include Theodore Roosevelt National Park (TRNP) and Lostwood National Wilderness Area (NWA). Locations of North Dakota Class I areas, IMPROVE monitor sites, and major visibility-affecting sources are depicted in Figure 1-3.

2 Regional Haze Metrics

Metrics used to assess regional haze include light extinction and deciview. Calculation of light extinction from visibility affecting aerosols for the NDDoH regional haze analysis will be based on the "new" IMPROVE algorithm[7]. This new equation was seen to reduce bias associated with use of the "old" IMPROVE algorithm, and was adopted as an alternative by the IMPROVE Steering Committee in December 2005. The new algorithm splits ammonium sulfate, ammonium nitrate, and organic mass concentrations into two fractions: small and large. The new algorithm for light extinction is:

$$
\begin{aligned}
b_{ext} = \; & 2.2 \times f_s(RH) \times [\text{small sulfate}] + 4.8 \times f_L(RH) \times [\text{large sulfate}] \\
& + 2.4 \times f_s(RH) \times [\text{small nitrate}] + 5.1 \times f_L(RH) \times [\text{large nitrate}] \\
& + 2.8 \times [\text{small organic mass}] + 6.1 \times [\text{large organic mass}] \\
& + 10.0 \times [\text{elemental carbon}] \\
& + 1.0 \times [\text{fine soil}] \\
& + 1.7 \times f_{ss}(RH) \times [\text{sea salt}] \\
& + 0.6 \times [\text{coarse mass}] \\
& + \text{Rayleigh scattering (site-specific)} \\
& + 0.33 \times [NO_2 \text{ (ppb)}]
\end{aligned}
$$

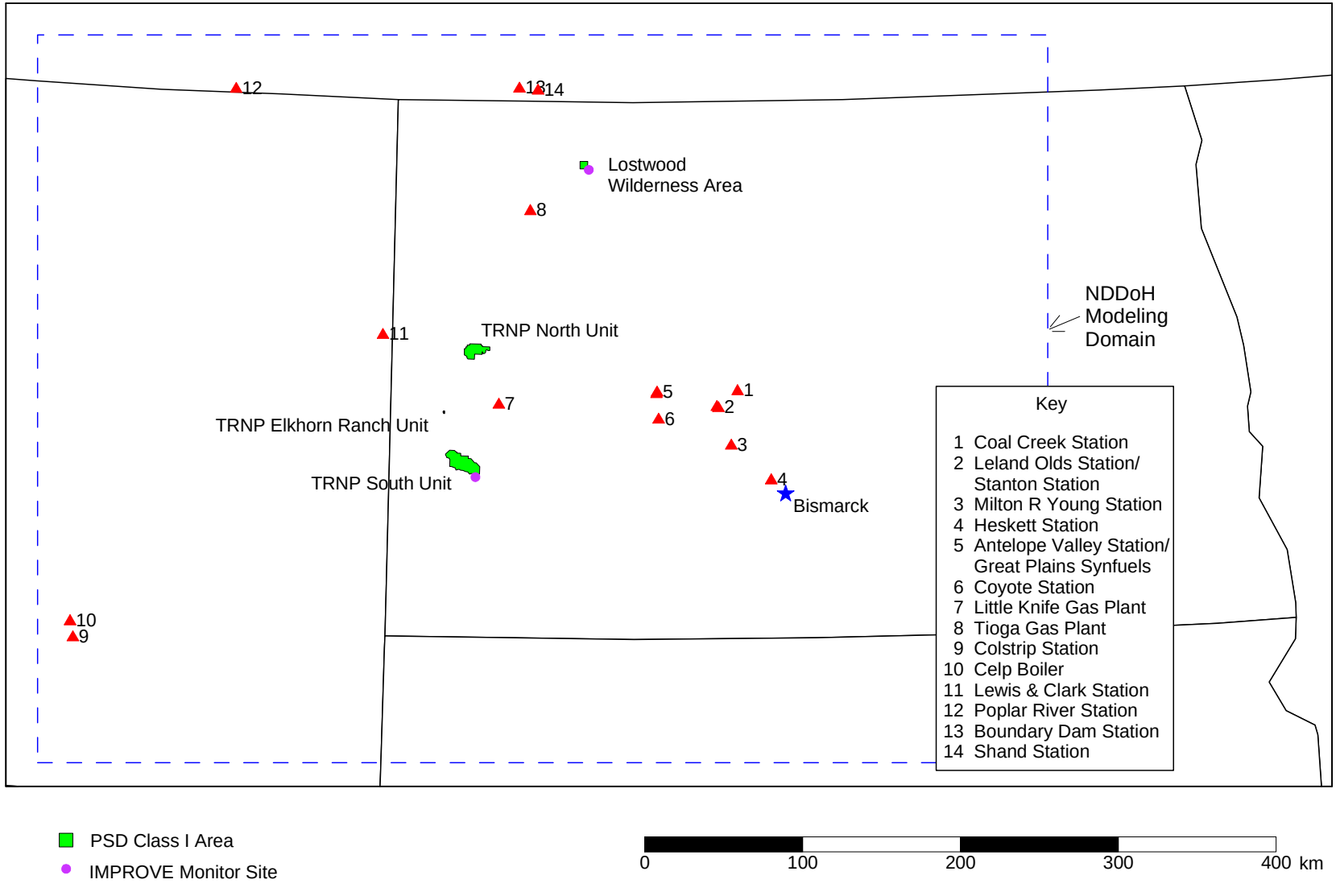
where

b_{ext} = light extinction in units of inverse megameters (Mm^{-1}),
$f_s(RH)$ = function of relative humidity for small size fraction,

[6] EPA, 2007. Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze. Publication No. EPA 454/B-07-002, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

[7] IMPROVE, 2005. New IMPROVE algorithm for estimating light extinction approved for use. The IMPROVE Newsletter, Volume 14, Number 4. Air Resource Specialists, Inc., Fort Collins, CO 80525.

Figure 1-3
Major Sources and PSD Class I Areas



$f_L(RH)$ = function of relative humidity for large size fraction,
$f_{ss}(RH)$ = function of relative humidity for sea salt,
all species concentrations are provided in ug/m^3,
sulfate/nitrate implies ammonium sulfate / ammonium nitrate.

Apportionment of total sulfate concentrations into small and large size fractions is defined:

$$[\text{large sulfate}] = \frac{[\text{total sulfate}]}{20\ ug/m^3} \times [\text{total sulfate}], \quad \text{for } [\text{total sulfate}] < 20\ ug/m^3$$

$$[\text{large sulfate}] = [\text{total sulfate}], \quad \text{for } [\text{total sulfate}] \geq 20\ ug/m^3$$

$$[\text{small sulfate}] = [\text{total sulfate}] - [\text{large sulfate}]$$

The same equations are used to apportion nitrate and organic mass size fractions.

WRAP and the NDDoH have determined that the NO_2 term has very little impact on total extinction, and the IMPROVE network does not include NO_2 monitoring. A review of observational NO_2 data from an NDDoH monitoring site in Theodore Roosevelt National Park revealed that readings were less than the minimum detectable level of 2.0 ppb more than 80% of the time in 2002. WRAP has not accounted for the NO_2 term in it's analyses for future visibility. Accordingly, the NDDoH proposes to omit the NO_2 term when implementing the new extinction algorithm.

Regarding the sea salt term in the extinction equation, very little impact from sea salt is expected in North Dakota. However, IMPROVE monitoring data in North Dakota Class I areas does occasionally include small values for sea salt. Because of the negligible impact of sea salt in the IMPROVE equation for North Dakota Class I areas, the impact would remain negligible even if some variation in sea salt occurs in the future. Therefore, sea salt will be omitted from the modeling process and an RRF of 1.0 will be assumed.

Light extinction is converted to deciview using the following relationship:

$$dv = 10 \times \ln(b_{ext} / 10)$$

where

dv = deciview
b_{ext} = light extinction in units of inverse megameters (Mm^{-1})

Visibility goals are generally expressed as deciviews. A change of one deciview represents a generally perceptible change in visibility to most people.

3 Overview of Methodology

3.1 General

Methodology for NDDoH projection of future visibility is based on EPA *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze* [8]. The guidance proposes a relative modeling approach to project future (2018) visibility, in order to determine compliance status with respect to visibility goals at Class I areas. Implementation of the relative modeling approach relies on relative response factors (RRF's) which represent the modeled impact of the future (visibility affecting) source inventory divided by the modeled impact of the baseline source inventory at Class I areas. These RRF's are applied to baseline IMPROVE monitoring data to project future visibility.

Projection of future visibility is needed for the 20% worst and 20% best visibility days at each Class I area. The 20% worst days and 20% best days are determined from Class I area IMPROVE monitoring data for each year for the 5-year baseline period 2000-2004. Because IMPROVE sampling occurs once every three days, the maximum number of monitored days per year would be 122, and the maximum number of 20% worst (best) days per year would be 24.

According to the EPA guidance, RRF's are developed by comparing the future average predicted concentration for 20% worst days (best days) to the baseline average predicted concentration for 20% worst days (best days), for each species. The 20% worst (best) modeled days are selected for consistency with the worst (best) monitored days (i.e., represent the same temporal periods), assuming modeling is based on 2000-2004 meteorological data. For each visibility affecting species (SO_4, NO_3, OMC, EC, Soil, CM), a single RRF is developed for each Class I area. The RRF is calculated by dividing the predicted future concentration averaged over all worst (best) days by the predicted baseline concentration averaged over all worst (best) days. Then, future concentrations for each species are projected by multiplying the RRF by the observed species concentration on each of the baseline worst (best) days.

The RRF approach can be expressed mathematically:

$$X^{i,j}_{of} = X^{i,j}_{ob} (RRF^i) = X^{i,j}_{ob} (\bar{X}^i_{pf} / \bar{X}^i_{pb})$$

where

$X^{i,j}_{of}$ represents projected **o**bserved **f**uture concentration for species i on day j (each of 20% worst days for each baseline year),

$X^{i,j}_{ob}$ represents **o**bserved **b**aseline (IMPROVE data) concentration for species i on day j (each of 20% worst days for each baseline year),

[8] See Supra note 6

$\bar{X}^i_{pf}$ represents average **p**redicted **f**uture concentration for species i (average of 20% worst days),

$\bar{X}^i_{pb}$ represents average **p**redicted **b**aseline concentration for species i (average of 20% worst days),

RRF^i represents the relative response factor for species i.

The projected future worst-day (best-day) concentrations are converted to light extinction using the IMPROVE equation, then daily light extinction is converted to deciview for each day. Finally, projected daily deciview is averaged over all worst-case (best-case) days for each year, then averaged over all years to produce the single future value needed to address visibility goals for each Class I area.

The NDDoH will implement the approach described above. The WRAP RMC has previously developed emission inventories (baseline and future), conducted modeling, and projected future visibility for the WRAP region Class I IMPROVE sites using the CMAQ grid model[9]. But to address weight of evidences issues, and possibly concerns about the resolution of the WRAP CMAQ simulations, the NDDoH needed an in-house modeling capability. The RMC is applying CMAQ on a National basis using a grid resolution of 36 km, with no plume-in-grid treatment. As such, dilution of point source plumes, and the speed of chemical reactions for species contained in the plume, may be overstated, particularly for large sources located relatively near Class I areas.

The NDDoH proposes to apply a hybrid modeling procedure by nesting the local NDDoH CALPUFF domain within the WRAP National CMAQ domain, and applying the Lagrangian CALPUFF model in a retrospective sense to more realistically define plume geometry for local point sources. To implement the nesting, hourly output concentrations from WRAP CMAQ will be used to set hourly boundary conditions for CALPUFF. The NDDoH will prepare baseline and future emission inventories for the CALPUFF domain, and will include the effect of proposed BART controls in the future inventory. CMAQ output used to set CALPUFF boundary conditions will reflect corresponding WRAP cases for baseline and future emission inventories. After this modeling system has been applied, the baseline and future case output from CALPUFF will be used to develop RRF's.

The hybrid modeling approach will be used for simulation of SO_2-SO_4-NO_X-HNO_3-NO_3 chemistry and transport, and thus sulfate and nitrate predictions, only. The larger sources located relatively near North Dakota Class I areas, where CMAQ dilution is a concern, are primarily emitters of SO_2 and NO_X. Further, IMPROVE measurements at North Dakota Class I areas indicate that sulfate and nitrate are primary contributors to light extinction on most worst-case days. Individual species contribution to light extinction for worst-case days at Theodore

[9] See Supra note 2

Roosevelt National Park is illustrated in Figure 3-1. Therefore, weight of evidence assessments will be most applicable to sulfate and nitrate species.

For all other visibility-affecting species, including OMC, EC, Soil, and CM, predictions needed for developing RRF's will be taken directly from CMAQ output. WRAP CMAQ output from the grid cell containing the subject Class I area IMPROVE site for baseline and future cases will be utilized. In this way, the NDDoH will take advantage of the extensive work WRAP has undertaken to develop accurate model emissions inventories for OMC-EC-Soil-CM species and precursors. CMAQ output for these species will be combined with hybrid modeling results for sulfate and nitrate in order to project future concentrations necessary for light extinction calculations for worst (best) days.

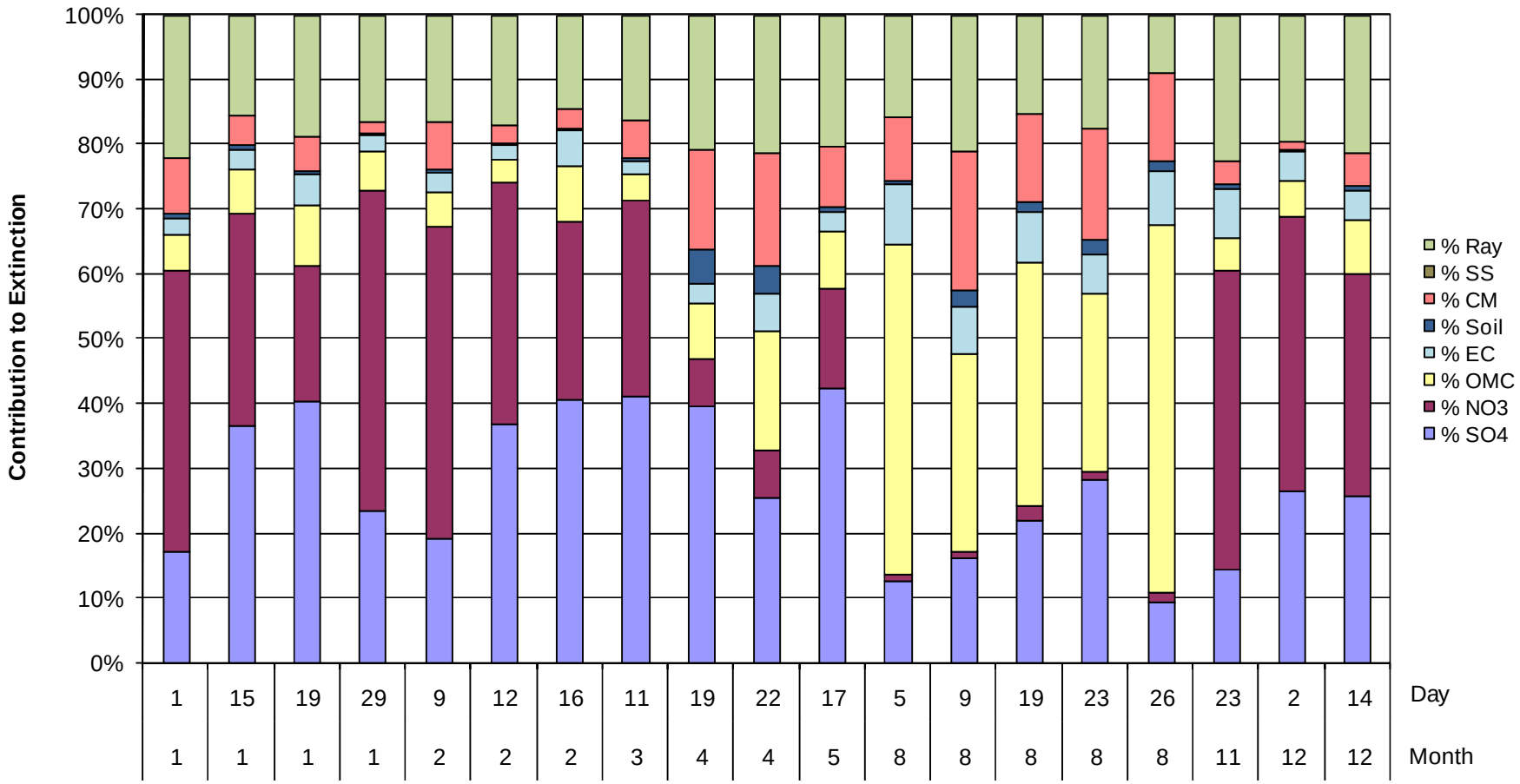
Along with setting boundary conditions, WRAP CMAQ data will be used for developing area source emissions inventories within the CALPUFF domain. The NDDoH will develop it's own point source inventory for SO_2 and NO_X, but will rely on WRAP CMAQ data for all other source categories (and for point source SO_4 and NO_3) to apportion emissions within the CALPUFF domain. WRAP is using the SMOKE emissions model[10] to develop the emissions inventory for CMAQ. The NDDoH will request and further process SMOKE output to define area source emissions for the CALPUFF domain. The CALPUFF area source emissions inventory will include the species SO_2, SO_4, NO_X, and NO_3. In addition, primary SO_4 and NO_3 emissions data will be extracted from the SMOKE inventory for point sources, and apportioned to the CALPUFF domain as area sources. WRAP CMAQ source categories to be included in the CALPUFF emissions inventory are outlined in Table 3-1. Note that WRAP SMOKE output did not contain all four species for some source categories.

Table 3-1
CMAQ-CALPUFF Area Source Categories

Source Category	Species Included
All Fires	SO_2, NO_X, SO_4, NO_3
Biogenics	NO_X
Fugitive Dust	SO_4, NO_3
On-Road Mobile	SO_2, NO_X, SO_4
Off-Road Mobile	SO_2, NO_X, SO_4, NO_3
Road Dust	SO_4, NO_3
Oil & Gas	SO_2, NO_X
Conventional Area	SO_2, NO_X, SO_4, NO_3
Point	SO_4, NO_3

[10] University of North Carolina, 2007. SMOKE User's Manual. The Institute for the Environment, University of North Carolina.

Figure 3-1
IMPROVE 20% Worst Days – TRNP 2000



The proposed interfacing of CMAQ and CALPUFF modeling systems for the hybrid approach is illustrated in the flow diagram in Figure 3-2. Necessary software for processing SMOKE emissions and CMAQ concentration data will be developed by the NDDoH. The software will be made available for public review.

Prior to baseline and future case CALPUFF modeling, the NDDoH will undertake a model performance evaluation. This evaluation will focus on the performance of the hybrid CMAQ-CALPUFF modeling system for sulfate and nitrate. As indicated previously, the CMAQ performance evaluations conducted by WRAP for OMC, EC, Soil, and CM species also apply.

The NDDoH will obtain CMAQ emissions input data (SMOKE output) and hourly concentration output files from the WRAP RMC. CMAQ data used to set CALPUFF boundary conditions and develop the CALPUFF area source inventory will be based on WRAP cases BASE02b, PLAN02d, and PRP18a, for performance evaluation, baseline case, and future case modeling, respectively. These WRAP scenarios are described as follows.

- Case BASE02b reflects CMAQ modeling using year 2002 emissions with year 2002 meteorology. WRAP is using this case for performance evaluations.

- Case PLAN02d reflects CMAQ modeling using composite 2000-2004 emissions with 2002 meteorology. WRAP is using this case for the base period to generate relative response factors.

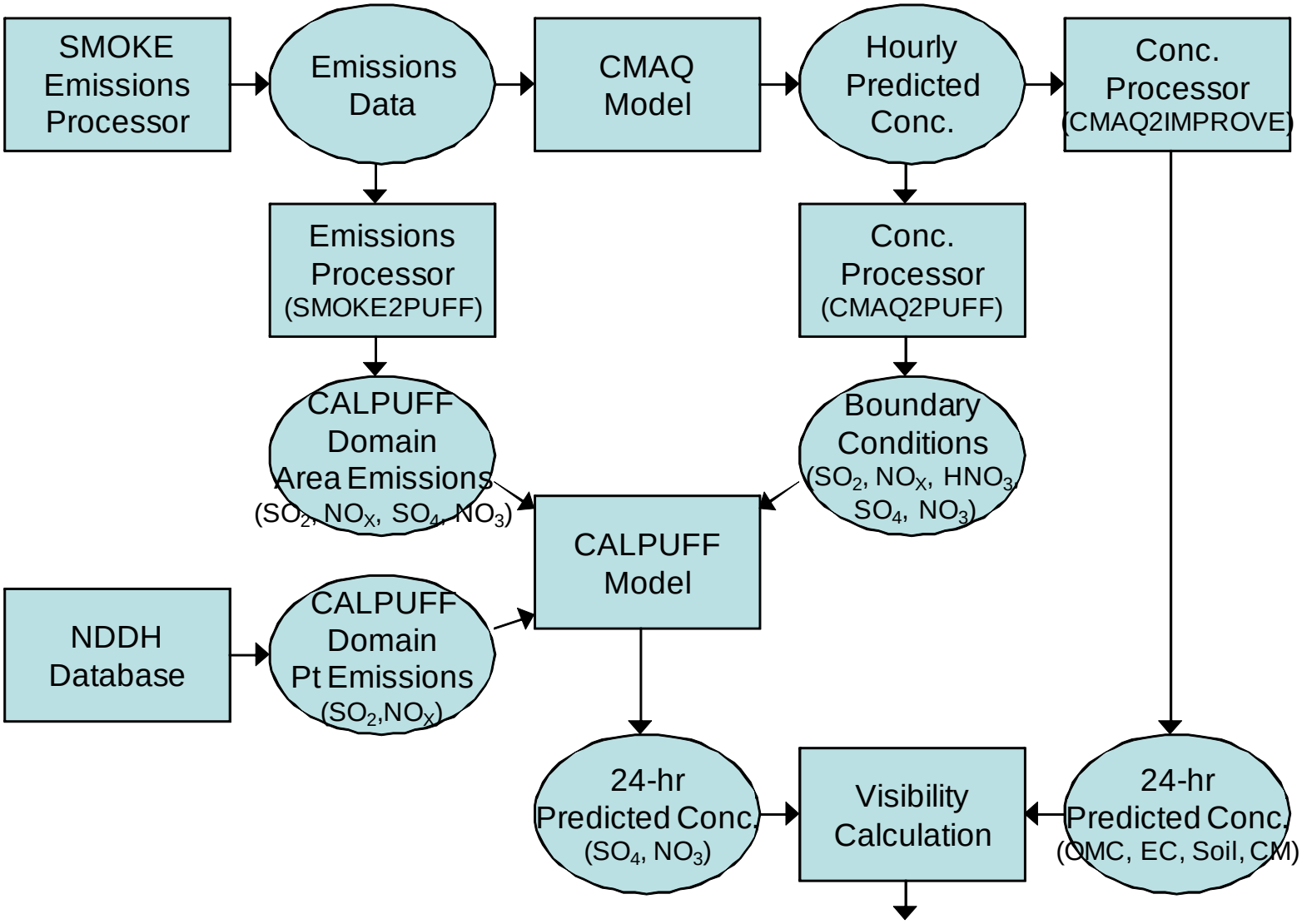
- Case PRP18a (Preliminary Reasonable Progress 18a) reflects CMAQ modeling using projected year 2018 emissions with 2002 meteorology. Case PRP18a represents base period emissions projected to 2018, accounting for preliminary estimates of the effect of BART controls, and assuming other growth and control factors. WRAP is using this case for the future period, on an interim basis, to generate relative response factors.

WRAP will eventually be refining it's PRP18a case in order to more accurately represent the effect of BART and other controls. The NDDoH will request data from the updated CMAQ case(s) when available, and revise the future case modeling.

WRAP RMC has conducted CMAQ modeling for the above cases using 2002 meteorological data, only. Therefore, the hybrid modeling conducted by the NDDoH will be limited to this single year of meteorological data. The RRF's developed from 2002 modeling will be applied to all five years of baseline monitoring data (2000-2004) to project future visibility. To the extent applicable, CALMET-CALPUFF input settings for regional haze modeling will be consistent with those specified in the North Dakota BART modeling protocol[11].

[11] NDDoH, 2005. Protocol for BART-Related Visibility Impairment Modeling Analyses in North Dakota. North Dakota Department of Health, Bismarck, ND 58501.

Figure 9-4
Interfacing of CMAQ and CALPUFF Modeling Systems



The versions of CALPUFF and associated programs which the NDDoH will utilize for regional haze modeling are summarized in Table 3-2.

Table 3-2
CALPUFF System Versions
Applicable For Regional Haze Modeling

Program	Version	Level
CALMET	5.8	70623
CALPUFF	5.8	70623
POSTUTIL	1.56	70627
CALPOST	5.6394	70622

Specifics of the NDDoH plan for projecting future visibility are outlined in Section 4.

3.2 Normalizing Hybrid Model RRF to WRAP CMAQ RRF

Based on initial performance testing conducted by NDDoH, the hybrid CMAQ-CALPUFF modeling system performs well in replicating observed concentrations of SO_4 and NO_3 (see Appendix A). However, performance regarding sensitivity to changes in emissions appears less robust, with CMAQ-CALPUFF overstating future case nitrate formation compared to predictions obtained by WRAP using CMAQ alone. For this reason, the NDDoH is proposing to modify the methodology for projection of future visibility by normalizing or standardizing the hybrid CMAQ-CALPUFF RRF to the CMAQ RRF obtained by WRAP, for species SO_4 and NO_3. This normalized approach can be expressed:

$$RRF^{i,k} = \text{WRAP CMAQ } RRF^{i} \quad \frac{\text{Hybrid Model production } RRF^{i,k}}{\text{Hybrid Model CMAQ emulation } RRF^{i,k}} \qquad (3\text{-}1)$$

where

RRF^{i} represents the EPA default relative response factor for species i (specific days for PLAN02d and PRP18a,

$RRF^{i,k}$ represents the relative response factor for species i and NDDoH scenario k,

Hybrid Model production RRF represents the result from the weight of evidence modeling step (see Sections 4.4, 4.5),

Hybrid Model CMAQ emulation RRF represents the result from the CMAQ emulation modeling step (see Section 4.6)

Note that the production RRF varies for each weight of evidence scenario, while the CMAQ emulation RRF remains constant for all weight of evidence scenarios. This is because all weight of evidence scenarios are normalized to the single (EPA default) modeling scenario conducted by WRAP

By standardizing or normalizing RRF's to the default CMAQ values obtained by WRAP, this approach acknowledges the sophistication of CMAQ chemistry compared to CALPUFF chemistry, especially the CMAQ sensitivity to changes in emissions. But the approach also retains the benefits of CALPUFF in providing better definition of point sources, plumes, and receptors. As discussed earlier, CMAQ-CALPUFF integration allows the NDDoH to explore future visibility impact from various local weight of evidence options which were not included in WRAP modeling. All weight of evidence scenario CMAQ-CALPUFF RRF's will be normalized to the WRAP CMAQ default RRF.

As indicated in Equation 3-1, the normalization scheme requires an RRF based on hybrid CMAQ-CALPUFF emulation of the WRAP CMAQ default configuration. CALPUFF inputs must be set so that the CMAQ-CALPUFF run replicates WRAP CMAQ as closely as possible. Though it is acknowledged that CALPUFF cannot reproduce the CMAQ chemistry, the configuration of emissions and receptors in CALPUFF can be adjusted to more closely emulate the WRAP CMAQ configuration. Software will be developed to allocate all point source emissions to a CALPUFF 36-km area source grid. The CALPUFF "effective height" (plume height) and "initial sigma z" area source input parameters will be used to assign point source emissions to discrete vertical "layers" which are consistent with WRAP CMAQ layers. Effective height will be based on stack height plus plume rise as calculated in the software.

Receptor resolution in WRAP CMAQ is limited to the average concentration in the 36-km surface grid cell volume containing the Class I area IMPROVE site. To emulate in CALPUFF, the predicted concentration will reflect the average over a uniform receptor grid placed within the CALPUFF area-source 36-km grid cell containing the IMPROVE site. Receptors will be spaced at 3 km for a total of 12 x 12 or 144 receptors for each Class I area. Elevation for each receptor will reflect the value used for the CALPUFF area-source grid cell.

Note that no changes to CALMET inputs (and thus the meteorological data set) are required for the emulation scenario. The ammonia background concentrations (emulation scenario) used with POSTUTIL will be derived from CMAQ output, which includes the ammonia species. Hourly ammonia concentrations will be taken from the CMAQ grid cells containing the North Dakota IMPROVE monitoring sites.

WRAP CMAQ RRF's (specific day option) are provided in Table 3-3.

Table 3-3
WRAP CMAQ RRF
(Specific Day Option)

	TRSU Worst D	TRSU Best D	Lost Worst D	Lost Best D
SO_4	0.92	1.02	0.91	1.02
NO_3	0.92	0.93	0.96	0.89
OMC	1.01	1.01	1.05	1.01
EC	0.72	0.78	0.73	0.74
Soil	1.13	1.08	1.11	0.96
CM	1	1	1	1

An example may clarify the normalization process. If, for 20% worst days at TRSU, one obtains an SO_4 RRF of 0.95 from the hybrid model production modeling step (call it weight of evidence scenario 1), and an SO_4 RRF of 0.99 from the hybrid model CMAQ emulation modeling step, the resultant final RRF for SO_4 becomes 0.92(0.95/0.99) or 0.88. In other words, instead of relying on the WRAP RRF of 0.92 to project future SO_4 concentratons, the RRF value has been "corrected" to 0.88 based on assumptions in the weight of evidence scenario 1, and the difference in treatment of emissions/receptors in CMAQ vs. hybrid modeling systems.

4 Detailed Visibility Projection Plan

1. Obtain/prepare CMAQ-related data from WRAP/RMC.

    a. Obtain CMAQ 36-km hourly concentration output files for BASE02b, PLAN02d, and PRP18a modeling cases (also for updated PRP18a cases when available). These data will be used to set SO_2-SO_4-NO_X-HNO_3-NO_3 boundary conditions for CALPUFF, and provide direct estimates of OMC, EC, Soil, and CM for calculation of visibility.

    b. Obtain CMAQ (SMOKE) 36-km gridded area source emissions data (annual) used for cases BASE02b, PLAN02d, and PRP18a modeling cases (also for updated PRP18a cases when available). These data will be used to apportion area source emissions for CALPUFF modeling.

    c. Develop/implement software to convert CMAQ hourly output for SO_2-SO_4-NO_x-

HNO_3-NO_3 to hourly boundary condition input for CALPUFF. Conversion procedure will focus on CMAQ output for grid cells in vicinity of perimeter of NDDoH CALPUFF domain.

d. Develop/implement software to extract CMAQ hourly output concentrations for OMC, EC, Soil, and CM for grid cells containing TRNP and Lostwood IMPROVE monitors. These concentrations will be used directly in calculation of daily light extinction for these Class I areas (recall that CALPUFF simulation will provide SO_4 and NO_3 species only).

e. Establish 36 km CALPUFF grid structure for area source emissions. This 36 km area source grid will be aligned with the basic NDDoH CALMET 3 km meteorological/computational grid.

f. Develop/implement software/procedure to apportion CMAQ 36-km gridded (area source) annual emissions data to CALPUFF 36-km grid cells for species NO_2-NO-NO_3-SO_2-SO_4. The software must account for the use of different Lambert projections in CMAQ and CALPUFF coordinate systems. Also, the CMAQ NO and NO_2 species must be combined to form the NO_X species used by CALPUFF.

2. Review five-year base period (2000-2004) IMPROVE monitoring data to determine 20 % worst/best days at TRNP South Unit and Lostwood NWA Class I areas.

a. Obtain raw IMPROVE data containing daily deciview for each Class I area from "TSS" web site (http://vista.cira.colostate.edu/tss/) for 2000-2004. For each Class I area and each year, rank days from highest to lowest deciview.

b. Based on ranked daily deciview, determine 20% worst and 20% best visibility days for each year for each Class I area. Before determining 20% worst and 20% best days, eliminate any days with missing data for extinction calculation.

c. Optional (weight of evidence) - Examine species composition and met. data for worst days in order to estimate primary source of emissions. Develop/implement objective criteria to discard each 20% worst day (for each year) where primary contribution to total deciview comes from sources over which the NDDoH has no regulatory control (e.g., natural emission source). Determine whether appropriate to substitute for discarded days from remaining ranked pool. Use adjusted inventory of 20% worst days to calculate average deciview, below. Note that this optional screening is not intended to apply to Canadian emissions, as a more direct method for discounting impact of those emissions is proposed (see Section 5).

3. Conduct a performance evaluation of the CMAQ-CALPUFF hybrid modeling system for SO_4 and NO_3 using 2002 meteorology, 2002 emissions, and 2002 IMPROVE observations.

a. Use WRAP CMAQ hourly output for SO_2-SO_4-NO_X-HNO_3-NO_3 to set hourly

boundary conditions for CALPUFF. CMAQ hourly output will be drawn from WRAP Case BASE02b, which is consistent with the scenario WRAP is using to test CMAQ performance.

b. Develop local emissions inventory for SO_2 and NO_X point sources located within the NDDoH CALPUFF domain. Inventory will be based on emissions for Year 2002. Point source data, with exception of oil and gas related sources, will be taken from the NDDoH modeling database, State of Montana, and Canada. Source data for oil and gas related emissions will be taken from the NDDoH / Oil and Gas Division's joint database. Actual emission rates, annual tons per operating hour, will be used for major sources. If time permits, application of seasonal emissions profiles will also be considered. Where CEM's data is available, the NDDoH may consider use of hourly emission rates.

c. Develop local emissions inventory for SO_2-SO_4-NO_X-NO_3 area sources located within the NDDoH CALPUFF domain. Area source data will be based on the WRAP area source inventory for 2002. CMAQ (SMOKE) 36-km gridded data for case BASE02b, apportioned to CALPUFF 36-km grid structure, will constitute the area source inventory. State quarterly emissions data from the "TSS" web site (http://vista.cira.colostate.edu/tss/) for case BASE02b will be used to apply quarterly (seasonal) profiles to the annual WRAP data. Source categories to be included in the area source inventory were outlined in Table 3-1.

d. Apply CALPUFF modeling system (CALMET-CALPUFF-POSTUTIL-CALPOST) for SO_2-SO_4-NO_X-NO_3 source inventories and boundary conditions as outlined above. Execution of the CALPUFF modeling system will be based on the NDDoH BART visibility modeling protocol[12] and the following additional input conditions:

   i. Apply modeling system for Year 2002 emissions/meteorology, only.
   ii. Specify receptors for TRNP South Unit and Lostwood NWA IMPROVE monitor locations, only (two receptors).
   iii. CALPUFF emission factors will be used to facilitate sources for which temporal emission profiles have been applied.
   iv. Apply the ammonia limiting method using POSTUTIL.

e. Prepare statistical summary of hybrid system performance for sulfate and nitrate. Statistics will be based on EPA *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze*[13] (Section 18). Assessment of performance will focus on accuracy for 20% worst day average, and on the sensitivity of the modeling system to respond to changes in emissions.

[12] See Supra note 11

[13] See Supra note 6

f. Changes to CALMET-CALPUFF inputs, such as the configuration of emission inventories, which may improve performance and are scientifically defensible will be considered. Effectiveness of these changes will be addressed in a follow-up performance evaluation (i.e., repeat Steps d and e, above).

Note that NDDoH has conducted a preliminary performance evaluation, consistent with the procedure outlined above, which is described in Appendix A of this document.

4. Conduct RRF base period (2000-2004) production modeling for SO_4 and NO_3 using hybrid CMAQ-CALPUFF modeling system with 2002 meteorology.

   a. Use WRAP CMAQ hourly output for SO_2-SO_4-NO_X-HNO_3-NO_3 to set boundary conditions for CALPUFF. CMAQ hourly output for setting CALPUFF base period boundary conditions will be drawn from WRAP Case PLAN02d, which represents a composite emission scenario for the period 2000-2004.

   b. Develop local emissions inventory for SO_2 and NO_X point sources located within the NDDoH CALPUFF domain. Using the 2002 inventory developed for the performance evaluation (2b, above), edit emission rates to reflect average of annual emissions for 2000-2004 (use of unedited 2002 values for oil and gas related sources and other smaller sources may be adequate). WRAP has suggested monthly scaling of emissions[14]. If time permits, consider application of temporal emission profile to larger sources, where applicable (e.g., EGU's, agricultural facilities).

   c. Develop local emissions inventory for SO_2-SO_4-NO_X-NO_3 area sources located within the NDDoH CALPUFF domain. Area source data will be based on the WRAP area source inventory for the base period, 2000-2004. CMAQ (SMOKE) 36-km gridded data for case PLAN02d, apportioned to CALPUFF 36-km grid structure, will constitute the area source inventory. State quarterly emissions data from "TSS" web site (case PLAN02d) may be used to apply quarterly (seasonal) profiles to the annual WRAP data. Source categories to be included in the area source inventory were outlined in Table 3-1.

   d. Apply CALPUFF modeling system (CALMET-CALPUFF-POSTUTIL) for SO_2-SO_4-NO_X-NO_3 source inventories and boundary conditions as outlined above. Execution of the CALPUFF modeling system will be based on the NDDoH BART visibility modeling protocol and the following additional input conditions:

      i. Changes to CALMET-CALPUFF input settings (if any) established in performance evaluation.
      ii. Apply modeling system for year 2002 meteorology, only.

[14] See Supra note 2

iii. Specify receptors for TRNP South Unit and Lostwood NWA IMPROVE monitor locations. For consistency with EPA guidance[15], additional receptors will be included to accommodate receptor averaging (accounts for possible inaccuracy of plume placement by the model) at both sites. A 3 x 3 grid of receptors, at 5 km spacing, will be centered on the IMPROVE monitor location.

iv. CALPUFF emission factors will be used to facilitate sources for which temporal emission profiles have been applied.

v. Apply the ammonia limiting method using POSTUTIL with hourly background values. Note that, if modeled scenario involves discounting the impact of Canadian sources (see Section 5), the 3-step ammonia limiting method must be applied to properly account for scavenging of ammonia by Canadian source emissions.

5. Conduct RRF future period (2018) production modeling for SO_4 and NO_3 using CMAQ-CALPUFF hybrid modeling system with 2002 meteorology.

   a. Use WRAP CMAQ hourly output for SO_2-SO_4-NO_X-HNO_3-NO_3 to set boundary conditions for CALPUFF. CMAQ hourly output for setting CALPUFF future period boundary conditions will be drawn from WRAP case PRP18a, which represents the preliminary projected emission scenario for 2018.

   b. Develop local emissions inventory for SO_2 and NO_X point sources located within the NDDoH CALPUFF domain. Using the 2002 inventory developed for RRF base period modeling (4b, above), annual emission rates / stack parameters will be edited to reflect expected changes by 2018 (use of unedited 2002 values for oil and gas related sources and other smaller sources may be appropriate). Point sources which have received or are likely to receive North Dakota (Montana, Canada?) air quality permits subsequent to 2004 will be added to the inventory. Sources which have shut down or are likely to shut down subsequent to 2004 and prior to 2018 will be deleted. For BART-applicable point sources, the NDDoH preferred BART control scenario will be used to develop 2018 annual emission rates and stack parameters (i.e., until BART control strategies are final). Temporal emission scaling will be applied as in the baseline point source inventory.

   c. Develop local emissions inventory for SO_2-SO_4-NO_X-NO_3 area sources located within the NDDoH CALPUFF domain. Area source data will be based on the WRAP area source inventory for the future period 2018. CMAQ (SMOKE) 36-km gridded data for case PRP18a, apportioned to CALPUFF 36-km grid structure, will constitute the area source inventory. State quarterly emissions data from "TSS" web site (case PRP18a) may be used to apply quarterly (seasonal) resolution to the annual WRAP data. Source categories to be included in the area source inventory were outlined in Table 3-1.

[15] See Supra note 6

d. Apply CALPUFF modeling system (CALMET/CALPUFF/POSTUTIL) for SO_2-SO_4-NO_X-NO_3 source inventories and boundary conditions as outlined above. Execution of the CALPUFF modeling system will be based on the NDDoH BART visibility modeling protocol and the following additional input conditions:

i. Changes to CALMET/CALPUFF input settings (if any) established in performance evaluation.
ii. Apply modeling system for year 2002 meteorology, only.
iii. Specify receptors for TRNP South Unit and Lostwood NWA IMPROVE monitor locations. For consistency with EPA guidance[16], additional receptors will be included to accommodate receptor averaging (accounts for possible inaccuracy of plume placement by the model) at both sites. A 3 x 3 grid of receptors, at 5 km spacing, will be centered on the IMPROVE monitor location.
iv. CALPUFF emission factors will be used to facilitate sources for which temporal emission profiles have been applied.
v. Apply the ammonia limiting method using POSTUTIL with hourly background values. Note that, if modeled scenario involves discounting the impact of Canadian sources (see Section 5), the 3-step ammonia limiting method must be applied to properly account for scavenging of ammonia by Canadian source emissions.

e. Revise future case modeling (repeat 5a, 5c, and 5d) using WRAP CMAQ output representing updates to case PRP18a, when available.

f. Optional (weight of evidence) - To discount the effect of Canadian sources on compliance with visibility goals, delete all Canadian sources from the CALPUFF future emissions inventory before applying model (see discussion *The Impact of International Sources on North Dakota Class I Areas* in Section 5).

6. Conduct CMAQ emulation modeling needed to implement the normalization step described in Section 3.2, using CMAQ-CALPUFF hybrid modeling system with 2002 meteorology. (Note that CMAQ emulation modeling is conducted only once, with the same result used for any weight of evidence option).

a. Modify the base and future period emissions inventories developed in above Steps 4 and 5 as follows:

i. Reallocate point source emissions to area sources consistent with CALPUFF 36-km area source grid structure.
ii. Use CALPUFF area-source “release height” and “initial sigma z” input parameters to configure all area sources (including those just created from point sources) in discrete “layers” consistent with WRAP CMAQ layers.

[16] See Supra note 6

iii. No modification necessary for boundary conditions (boundary condition resolution already 36 km).

b. Apply CALPUFF modeling system (CALMET-CALPUFF-POSTUTIL) for emission inventories and boundary conditions as outlined above, for both base and future period scenarios. Execution of the CALPUFF modeling system will be based on the NDDoH BART visibility modeling protocol and the following additional input conditions:

i. Changes to CALMET/CALPUFF input settings (if any) established in performance evaluation.
ii. Apply modeling system for year 2002 meteorology, only.
iii. Use uniform receptor grid spaced to fill the CALPUFF 36-km (area source) grid cell containing the TRNP South Unit and grid cell containing the Lostwood NWA IMPROVE monitor locations. Receptors will be spaced at 3 km for a total of 12x12 or 144 receptors for each Class I area.
iv. CALPUFF emission factors will be used to facilitate sources for which temporal emission profiles have been applied.
v. Apply the ammonia limiting method using POSTUTIL with WRAP CMAQ hourly background values.

7. Develop SO_4 and NO_3 relative response factors (RRF) using CMAQ emulation scenario modeling results. (Note that CMAQ emulation RRF's are developed only once, and the same values are used for any weight of evidence option.)

a. Extract CALPUFF daily (24-hour) predicted concentrations for the days consistent with the 20% worst days identified in IMPROVE monitoring data for 2002. Calculate the average of the daily SO_4 and NO_3 predictions for these days, for both baseline and future period scenarios. Repeat procedure for each Class I area.

b. Calculate 20% worst day RRF's for each species (SO_4, and NO_3) as the ratio of the future average worst-day prediction to the baseline average worst-day prediction. Repeat for each Class I area.

c. Repeat a, b, above, for 20% best days.

8. Develop final relative response factors using baseline and future scenario production modeling results.

a. Extract CALPUFF daily (24-hour) predicted concentrations for the days consistent with the 20% worst days identified in IMPROVE monitoring data for 2002. Calculate the average of the daily SO_4 and NO_3 predictions for these days, for each scenario. Repeat procedure for each Class I area.

b. Calculate 20% worst day RRF's for SO_4 and NO_3 species as the ratio of the future

average worst-day prediction to the baseline average worst-day prediction. Repeat for each Class I area.

c. Use these RRF's, the CMAQ emulation RRF's from item7b, and the WRAP CMAQ RRF's from Table 3-3 to calculate the final RRF's for SO_4 and NO_3, using Equation 3-1. Repeat for each Class I area

d. Repeat a, b, and c, above, for 20% best days.

e. For OMC, EC, Soil, and CM species, take final RRF's from WRAP CMAQ modeling, as provided in Table 3-3.

f. For sea salt (SS), assume RRF of 1.0 for worst-days/best-days for both Class I areas.

9. Apply final RRF's to baseline monitoring data (2000-2004) to project future visibility for each Class I area .

a. Apply species-specific RRF's to 20% worst baseline monitored days in year 2000 to project future concentrations for each species for each day (the same species-specific RRF's are used for each day). Repeat for years 2001 through 2004.

b. Using the projected future concentrations for 20% worst days in year 2000, calculate light extinction (using new IMPROVE equation) and convert to deciview for each day. Repeat for years 2001 through 2004.

c. Calculate average worst-day future deciview from projected daily future deciview (7b), for each year (2000-2004). Then, calculate future five-year average worst-day deciview.

d. Repeat a, b, and c, above, for 20% best baseline monitored days.

e. Optional (weight of evidence) - Using the species-specific projections from items 8c and 8e, calculate five-year average future light extinction for each species for 20% worst days (to accommodate glide path goals for individual species).

10. Determine status with respect to 2018 visibility goals.

a. Compare five-year average projected future deciview for worst days (item 9c) with five-year average monitored baseline deciview for worst days (WRAP TSS), for each Class I area, to determine status with respect to visibility goals.

b. Compare five-year average projected future deciview for best days (item 9d) with five-year average monitored baseline deciview for best days (WRAP TSS), for each Class I area, to determine whether visibility has deteriorated.

c. Optional (weight of evidence) - Compare five-year average projected future light extinction for each species for worst days (item 9e) with five-year average monitored baseline extinction for each species for worst days (WRAP TSS) to determine status with respect to visibility goals for individual species.

5 The Impact of International Sources on North Dakota Class I Areas

5.1 Proposed Approach

In the process of analyzing progress with respect to visibility goals, it will be necessary for NDDoH to address the impact of Canadian sources north of the International border. One method, as part of a weight of evidence demonstration, would be to discount the effect of Canadian sources (over which the State has no regulatory control). This could be accomplished by eliminating the contribution of Canadian sources to baseline monitoring data used for visibility projections, eliminating Canadian sources from the modeled inventories used to develop RRF's, and developing an adjusted glide path for future visibility goals.

Recall that EPA guidance[17] provides that RRF's are developed by comparing the future average predicted concentration for 20% worst days (best days) to the baseline average predicted concentration for 20% worst days (best days), for each species. The species-specific RRF's are then applied to species-specific baseline monitored concentrations for each 20% worst day (best day), for each baseline year, to project corresponding future values. Finally, these future daily concentrations are converted to light extinction, then deciview, and averaged over all worst (best) days to project future deciview. This approach is incorporated in the NDDoH visibility projection plan (Section 4).

To discount the effect of Canadian sources, the RRF's are adjusted in the modeling process, and a modified glide path is developed.. As discussed in Section 3, the projection of future concentration can be expressed:

$$X^{i,j}_{of} = X^{i,j}_{ob}\,(RRF^{i}) = X^{i,j}_{ob}\,(\bar{X}^{i}_{pf}/\bar{X}^{i}_{pb}) \qquad (5\text{-}1)$$

where

$X^{i,j}_{of}$ represents projected **o**bserved **f**uture concentration for species i on day j (each of 20% worst days for each baseline year),

$X^{i,j}_{ob}$ represents **o**bserved **b**aseline (IMPROVE data) concentration for species i on day j (each of 20% worst days for each baseline year),

[17] See Supra note 6

$\bar{X}^i_{pf}$ represents average **p**redicted **f**uture concentration for species i (average of 20% worst days),

$\bar{X}^i_{pb}$ represents average **p**redicted **b**aseline concentration for species i (average of 20% worst days),

RRF^i represents the relative response factor for species i.

To discount the effect of Canadian emissions, the impact of Canadian sources is removed from Equation 5-1 variables, which provides

$$X^{i,j}_{of(us)} = X^{i,j}_{ob(us)} (\bar{X}^i_{pf(us)} / \bar{X}^i_{pb(us)}) \qquad (5\text{-}2)$$

where

(us) represents the Equation 5-1 variable with the impact of Canadian sources removed (impact of US sources and natural background, only)

Thus, baseline US observations which exclude the impact of Canadian sources, and future and baseline modeling results which exclude the impact of Canadian sources, would be required to project future US concentrations. While baseline and future modeled inventories can be easily adjusted to remove Canadian sources, adjustment of baseline observations to exclude Canadian source impact could be technically difficult.

It is reasonable instead to consider a modeling solution for the estimation of adjusted baseline concentrations. A factor representing the ratio of modeled impact of "all baseline sources less Canadian sources" to "all baseline sources" could be applied to adjust the observed baseline, as follows:

$$X^{i,j}_{ob(us)} = X^{i,j}_{ob} (\bar{X}^i_{pb(us)} / \bar{X}^i_{pb}) \qquad (5\text{-}3)$$

Substituting Equation (5-3) into Equation (5-2) provides

$$X^{i,j}_{of(us)} = X^{i,j}_{ob} (\bar{X}^i_{pb(us)} / \bar{X}^i_{pb}) (\bar{X}^i_{pf(us)} / \bar{X}^i_{pb(us)}) \qquad (5\text{-}4)$$

Finally, Equation (5-4) reduces to

$$X^{i,j}_{of(us)} = X^{i,j}_{ob} (\bar{X}^i_{pf(us)} / \bar{X}^i_{pb}) \qquad (5\text{-}5)$$

So Equation 5-5 provides a modeling solution for projecting future concentrations without the impact of Canadian sources. The adjusted RRF's ($\bar{X}^i_{pf(us)} / \bar{X}^i_{pb}$) would be inserted in the visibility projection plan item 8b to project future concentrations for each species for each day. Effectively, this approach is implemented by including Canadian sources in the baseline modeled

inventory, and excluding Canadian sources from the future modeled inventory (i.e., the weight of evidence option included as modeling plan item 5f).

To complete the source apportionment process, the impact of Canadian emissions must also be removed from the glide path used to assess visibility improvement progress. The revised glide path would be based on Equation 5-3, which provides a baseline starting point without the effect of Canadian emissions. The adjusted species-specific glide path is illustrated in Figure 5-1, for a case where Canadian emissions comprise one-half of total observed concentrations for sulfate.

One caveat associated with the use of the adjusted glide path is that the impact of US-only emissions will not be consistent with 2018 IMPROVE monitoring data (which will reflect the total impact of all sources). If the 2018 IMPROVE data are to be used to monitor visibility progress with respect to the adjusted 2018 goal, the impact of 2018 Canadian emissions will first have to be subtracted from the monitored observations.

The NDDoH proposes to apply the adjusted RRF's and glide path for 20% worst days only, as the impact of Canadian sources is not likely to be problematic in meeting visibility goals for best days. Because hybrid modeling will be applied only for S and N chemistry, the RRF adjustment would apply only to sulfate and nitrate species.

Note that other methods have been suggested for discounting the effect of international sources on visibility improvement progress. CENRAP has proposed several options for discounting the impact of international sources[18]. Montana has suggested an adjusted glide path where the impact of international sources is added onto the 2064 natural background, rather than subtracted from the baseline. Effectively, the Montana approach produces the same result as the procedure suggested here.

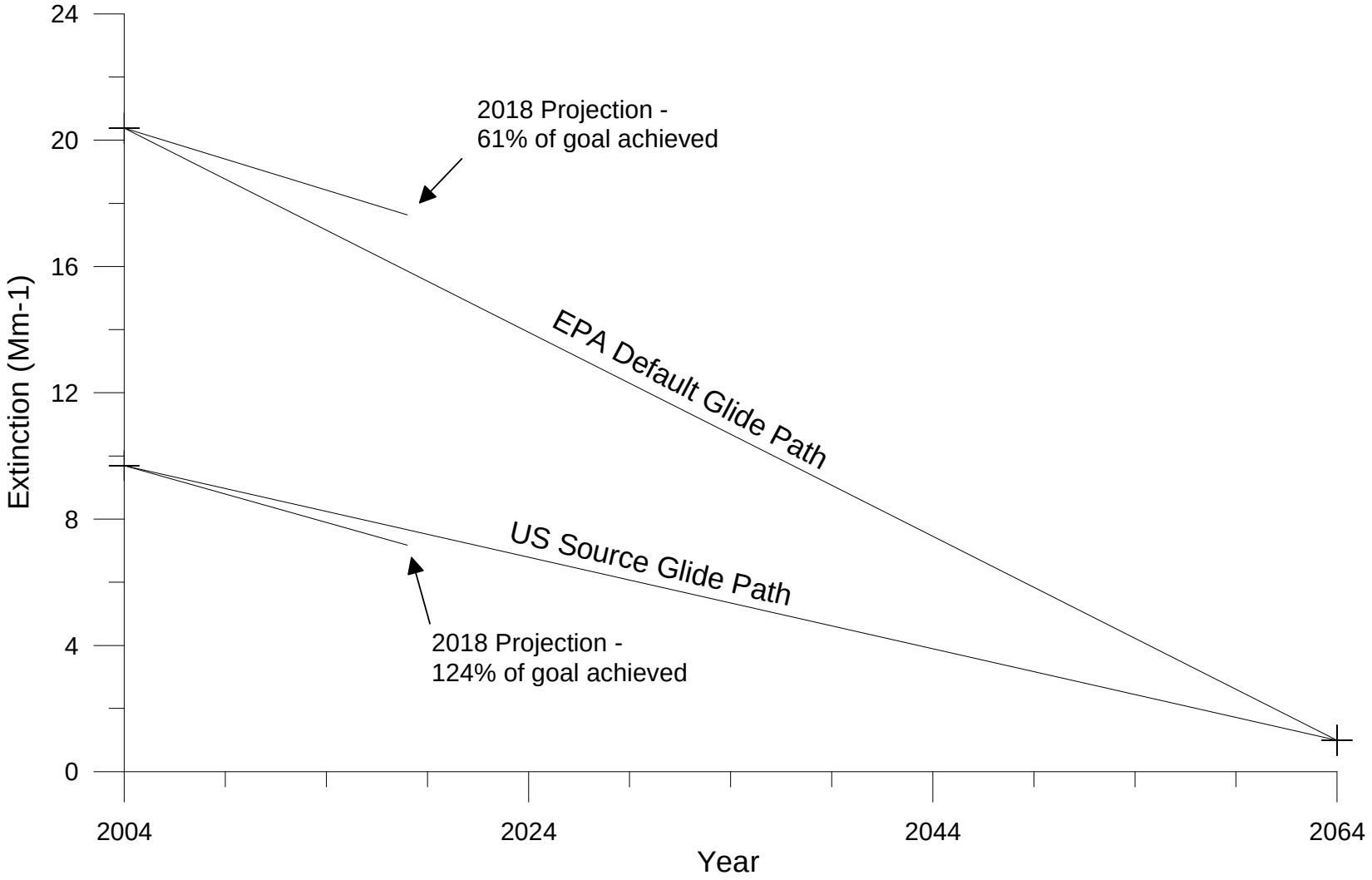
5.2 Illustration

A species-specific illustration may clarify the proposed approach. Consider a hypothetical US Class I area where Canadian emissions contribute one-half of the average observed sulfate concentration for 20% worst days. For this illustration, it is assumed there are only two worst-case monitored days. It is also assumed that impact of US sources (plus natural sources) will be 25% lower in 2018 compared to the baseline, and that the inventory/impact of Canadian sources remains unchanged between the baseline and 2018. Finally, to implement the new IMPROVE equation, values for $f_s(RH)$, $f_l(RH)$, and conversion from sulfate to ammonium sulfate are assigned as 2.7, 2.1, and 1.375, respectively. (For simplification, this illustration does not include WRAP CMAQ normalization.)

First, consider what happens if no adjustment is made, and the impact of Canadian sources

[18] CENRAP, 2007. CENRAP Policy Oversight Group (POG) - Summary of PM Source Apportionment Modeling and 2018 Projection Approaches. Power Point presentation, Joint Workgroup Meeting, Kansas City, Missouri, March 7, 2007.

Figure 5-1
Illustration of Visibility Improvement Using EPA Default Glide Path and US Source Adjusted Glide Path for Sulfate



remains in the IMPROVE baseline observations, and the modeled baseline and future emission inventories (future projection based on Equation 5-1):

1) Examination of IMPROVE monitor data for this Class I area reveals that May 30 and July 10 are the two worst 20% visibility days in 2002. The observed concentration of sulfate on May 30 is 2.5 ug/m3, and the observed concentration of sulfate on July 10 is 2 ug/m3.

2) Generate EPA default glide path for this Class I area (Figure 5-1). Species-specific starting point for this glide path is determined by converting observed baseline sulfate concentrations for 20% worst days (in this case 2.5 ug/m3 and 2.0 ug/m3) to light extinction (new IMPROVE equation), then averaging over all worst case days. This provides a value of 20.38 Mm^{-1}. The 2064 endpoint for this path is the natural background, which for sulfate is assumed at 1.0 Mm^{-1}.

3) Baseline and future emission inventories are developed which include all US and Canadian sources. The CALPUFF/CMAQ modeling system is executed for the baseline inventory and the future inventory.

4) Modeling results for May 30 show a baseline predicted sulfate concentration of 2.8 ug/m3, and a future predicted sulfate concentration of 2.45 ug/m3. Results for July 10 indicate a baseline predicted sulfate concentration of 2.4 ug/m3, and a future predicted sulfate concentration of 2.1 ug/m3. Note that these results are consistent with the assumptions, above.

5) To develop the RRF for worst-day sulfate, the average future prediction is divided by the average baseline prediction as follows:

$$RRF = ((2.45+2.1)/2) / ((2.8+2.4)/2) = 0.875$$

6) The RRF is applied to sulfate observations for worst-case baseline days to project future worst-case sulfate concentrations:

May 30 2.5 (0.875) = 2.19 ug/m^3
July 10 2.0 (0.875) = 1.75 ug/m^3

7) Using the new IMPROVE equation, projected sulfate concentrations are converted to light extinction, then averaged over all worst-case days. This provides an average projected extinction of 17.63 Mm^{-1}.

8) Finally, the average projected future light extinction is compared with the glide path goal. This is illustrated in Figure 5-1.

Now, the exercise is repeated using the suggested approach for discounting impact of Canadian sources (future projection based on Equation 5-5).

1) Examination of IMPROVE monitor data for a hypothetical Class I area reveals that May 30

and July 10 are the two worst 20% visibility days in 2002. The observed concentration of sulfate on May 30 is 2.5 ug/m3, and the observed concentration of sulfate on July 10 is 2.0 ug/m3.

2) Develop adjusted glide path using Equation 5-3 (Figure 5-1). Species-specific baseline starting point for this glide path is developed by applying Equation 3 to 20% worst day sulfate concentrations, then converting concentration to light extinction, and averaging over all worst case days. For this illustration, the baseline value is 9.69 Mm^{-1}. Again, the path terminates in 2064 at natural background, which is assumed at 1.0 Mm^{-1} for sulfate.

3) A baseline emission inventory is developed which includes all US and Canadian sources. A future emission inventory is developed which includes all US sources, but no Canadian sources. The CALPUFF/CMAQ modeling system is executed for the baseline inventory and the future inventory.

4) Modeling results for May 30 show a baseline predicted sulfate concentration of 2.8 ug/m3, and a future predicted sulfate concentration of 1.05 ug/m3. Results for July 10 indicate a baseline predicted sulfate concentration of 2.4 ug/m3, and a future predicted sulfate concentration of 0.9 ug/m3. Note that these results are consistent with illustration assumptions.

5) To develop the RRF for worst-day sulfate, the average future prediction is divided by the average baseline prediction as follows:

$$RRF = ((1.05+0.9)/2) / ((2.8+2.4)/2) = 0.375$$

6) The RRF is applied to sulfate observations for worst-case baseline days to project future worst-case sulfate concentrations:

May 30 2.5 (0.375) = 0.94 ug/m^3
July 10 2.0 (0.375) = 0.75ug/m^3

7) Using the new IMPROVE equation, projected sulfate concentrations are converted to light extinction, then averaged over all worst-case days. This provides an average projected extinction of 7.18 Mm^{-1}.

8) Finally, the average projected future light extinction is compared with the adjusted glide path goal. This is illustrated in Figure 5-1.

As indicated in Figure 5-1, with the EPA default method including all sources, 61% of the 2018 visibility goal is achieved. With the alternate approach excluding Canadian source impact, 124% of the 2018 goal is achieved.

Note that values used in this illustration for observed and modeled sulfate concentrations are completely hypothetical. The assumed 2064 natural background for sulfate, 1.0 Mm^{-1}, is consistent with values posted on the TSS web site for North Dakota Class I areas. However,

other natural background values have been suggested[19].

6 Weight of Evidence Options

The NDDoH will complete the default visibility projection plan as detailed in Section 4. But the Regional Haze Rule[20] specifies that the SIP may be based, in part, on evidence apart from results of the default projection methodology. For example, the analysis could logically be modified to discount the impact of visibility-affecting emission sources over which the NDDoH has no regulatory control.

Options which could be considered in the analysis of visibility goals include:

- Discounting the impact of Canadian source visibility-affecting emission sources (discussed in Section 5 and included in the Visibility Projection Plan as optional item 5f).

- Discard certain worst-case monitored days, before projecting future visibility, if it can be determined that primary species affecting light extinction on these days cannot be controlled by NDDoH. This approach is included as a "weight of evidence" option in the Visibility Projection Plan (item 2c).

- Use of species-specific visibility progress goals. This approach has been suggested by WRAP[21], and is incorporated in the Visibility Projection Plan as "weight of evidence" options (items 2f, 9e, and 10c).

- Basing 20% worst visibility days for determining RRF's on baseline model results rather than IMPROVE monitor data. This may be justified because neither CMAQ nor CALPUFF perform well on a "paired-in-time" basis. The resultant RRF's would still be applied to worst case IMPROVE days to project future visibility.

The above list is preliminary and not necessarily complete. The process or results of the visibility projection analysis may suggest other weight of evidence options the NDDoH will want to pursue.

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[19] EPA, 2003. Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program. Publication No. EPA-454/B-03-005, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

[20] See Supra note 1

[21] WRAP, 2007. Attribution of Haze Workgroup's Technical Recommendations on Monitoring Metrics for Regional Haze Planning (2/23/07 Draft).

7 CALHAZE Software

The NDDoH is developing software (CALHAZE) to automate the analysis of IMPROVE baseline monitoring data, the development of RRF's, and the projection of future visibility. To establish baseline monitored conditions, the software will access IMPROVE data downloaded from the "VIEWS" web site. To develop RRF's, the software will operate on the CALPUFF (POSTUTIL) hourly output files from baseline and future modeled scenarios. The new IMPROVE equation, along with weight of evidence options noted above, will be incorporated in the software.

This software will be made available for public review. In order to validate it's accuracy, CALHAZE output values for baseline conditions and default RRF's have been successfully cross checked with data on the WRAP "TSS" web site.

Appendix A
Hybrid CMAQ-CALPUFF Performance Evaluation

The North Dakota Department of Health (NDDoH) has conducted a limited operational evaluation to assess performance of the hybrid CMAQ-CALPUFF modeling system. The focus of the evaluation was to assess performance in reproducing observed concentrations of sulfate and nitrate at IMPROVE monitoring sites in North Dakota. These sites include the Theodore Roosevelt National Park South Unit (TRSU) and the Lostwood Wilderness Area. Alternative input options which might improve performance were also explored. To the extent applicable, the performance evaluation followed EPA guidance for Regional Haze modeling analyses[22].

Evaluation of performance was based on the plan outlined in Section 4.3 of the modeling protocol. WRAP CMAQ hourly concentration output (SO_2-SO_4-NO_X-HNO_3-NO_3) for Case BASE02B was used to set hourly boundary conditions for CALPUFF. The emissions inventory (SO_2-NO_X) for the point source category was developed using data from the NDDoH emissions database for 2002, and sources were configured as conventional point sources in CALPUFF. This inventory included point sources located in adjacent parts of South Dakota, Montana, and Canada, which are included in the NDDoH CALPUFF domain (see Figure 1-2). This inventory also included SO_2 emissions associated with oil and gas production facilities (treaters and flares) in North Dakota, which did not appear to be accounted for in the WRAP inventory for BASE02B. Emission rates for the point source inventory reflect actual emissions for Year 2002.

All other source categories (see Protocol Table 3-1) were treated as area sources in CALPUFF, and the emissions inventory (SO_2-SO_4-NO_X-NO_3) for these categories was based on WRAP CMAQ input (SMOKE output) for all sources other than point sources. Software was prepared and implemented to apportion the gridded SMOKE output emissions for BASE02B into a 36-km area source grid structure developed for the NDDoH CALPUFF domain, on a consistent spatial basis. Emission rates for this area source inventory reflect annual averages for the SMOKE data.

The CALPUFF modeling system (CALMET-CALPUFF-POSTUTIL-CALPOST) was applied for SO_2-SO_4-NO_X-NO_3 source inventories and boundary conditions as described above. For all other input conditions, execution of the CALPUFF modeling system was initially based on the

[22] EPA, 2007. Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze. Publication No. EPA 454/B-07-002, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

NDDoH BART visibility modeling protocol[23] using Year 2002 meteorology. Single receptors were placed at the TRNP and Lostwood IMPROVE sites. The ammonia limiting method was applied using POSTUTIL. Concurrent, monthly average ammonia data were taken from the NDDoH Beulah monitoring site.

After initial application of CALPUFF for the performance evaluation, it was concluded that certain scientifically-defensible adjustments to CALPUFF input conditions may improve performance for the hybrid modeling system, and should be investigated. Thus, the performance evaluation evolved into a suite of tests which are described below.

1) Test 1 - CALPUFF system executed with default input conditions, as outlined above. Air mass depth for boundary conditions was set to 2000 meters.

2) Test 2 - CALPUFF as in Test 1, but using CEMS 2002 hourly emissions data (SO_2, NO_X) for point sources, where available.

3) Test 3 - CALPUFF as in Test 1, but using WRAP MM5 12 km 2002 mesoscale data in CALMET, rather than the default NDDoH RUC 2002 mesoscale data.

4) Test 4 - CALPUFF as in Test 1, but increasing air mass depth for boundary conditions from 2000 to 3000 meters.

5) Test 5 - CALPUFF as in Test 1, but with addition of SO_4 and NO_3 emissions from point sources. (Previous tests excluded this component, because SO_4 and NO_3 emissions are not included in the NDDoH point source inventory. For Test 5, an SO_4-NO_3 emissions inventory was derived from SMOKE gridded output for the point source category, and configured as area sources for CALPUFF.)

6) Test 6 - CALPUFF as in Tests 4 and 5 (air mass depth = 3000 meters, SO_4 and NO_3 emissions from point sources included), but area sources configured as 4 groups to account for varying release heights, and Beulah hourly profile used for background NH_3 in POSTUTIL. (Area sources were configured as a single CALPUFF group in previous tests.)

7) Test 7 - CALPUFF as in Test 6, but Beulah hourly NH_3 profile doubled for Lostwood.

Results of the performance evaluation are summarized in Tables A-1 and A-2. Table A-1 compares predicted NO_3 and SO_4 concentrations to observed concentrations for both IMPROVE sites, while Table A-2 provides predicted-to-observed ratios. Note that both tables include a column labeled “CMAQ only”, which provides the original WRAP CMAQ results for Case BASE02B.

As shown in Tables A-1 and A-2, the three metrics selected to measure performance for this

[23] See Supra Note 11

evaluation are 90th percentile day concentration (24-hour average), average of 20% worst days concentration, and annual average concentration. The first two metrics were selected for consistency with the time scale that applies to regional haze modeling, i.e., average of the 20% worst or 20% best days. The third metric, annual average concentration, is a measure of the model's ability to accurately conserve total annual mass. The comparison between predicted and observed concentrations for the first two metrics is unpaired in time.

Results in Tables A-1 and A-2 indicate that the hybrid modeling system performed well, in general. Even for the default Test 1, predictions were well within a factor of two of observations. In most cases, the hybrid system predictions were closer to observations than predictions from CMAQ, alone. Table A-2 illustrates that the hybrid system slightly over-predicted observations for TRSU NO_3, and slightly under-predicted, otherwise.

A comparison of results for Tests 1 through 5 reveals very little difference in predictions. The implication is that the input changes reflected in Tests 2 through 5 did not add significant value to the predictions. The increased temporal resolution obtained by using the CEMS hourly emissions for applicable point sources (Test 2) provided no consistent improvement. Test 3 results suggest that the NDDoH RUC mesoscale data is consistent with the WRAP MM5 mesoscale data. Test 4 results indicate that CALPUFF is not very sensitive to boundary air mass depth. Even the addition of point source NO_3 and SO_4 emissions in Test 5 achieved no meaningful improvement in predictions, suggesting that sources configured as area sources in CALPUFF may have only a small contribution to the total prediction.

While the operational evaluation to compare predictions with observations was being conducted, the NDDoH also undertook a preliminary diagnostic evaluation[24] to assess the response of the hybrid modeling system to changes in NO_3 and SO_4 predictions. In response to significant reductions in both SO_2 and NO_X emissions, the NDDoH found that the hybrid system responded reasonably well with lower SO_4 predictions, but seemed to overstate NO_3 predictions for the reduced emission scenario. In fact, NO_3 concentrations actually increased under some assumptions, possibly an overreaction to the newly freed ammonia in the reduced SO_2 emissions scenario (SO_2 preferentially scavanges ammonia in the CALPUFF chemistry). This behavior was not seen in the WRAP CMAQ results for baseline versus future predictions.

To address the problematic NO_3 response, the NDDoH discussed the issue with Joe Scire (TRC)[25], a recognized CALPUFF expert in the regulatory modeling community. Mr. Scire indicated that TRC testing has shown that the NO_3 response may improve if hourly background ammonia is used rather than monthly average values. Also, Mr. Scire provided some insight on configuring area sources in CALPUFF to be more consistent with the area source treatment in CMAQ. This involves proper settings for the CALPUFF "release height" and "initial sigma z" input parameters for area sources. The NDDoH retested after incorporating Mr. Scire's

[24] See Supra note 22

[25] TRC, 2008. Telephone consultation with Joe Scire, May 29, 2008. Joe Scire, TRC Corporation, Lowell, MA 01854

suggestions, i.e., using hourly ammonia background and reconfigured area sources. Although the NO_3 response improved, predicted reductions were still not consistent with CMAQ.

As a result of the initial diagnostic performance testing, the NDDoH concluded that the use of hourly ammonia background concentrations is preferable to the use of monthly averages, and that CALPUFF inputs for area sources should be reconfigured. Additional operational evaluation tests (Tests 6 and 7) were thus conducted to determine how these changes would affect the comparison with observations. Test 6 was conducted by first assuming a boundary air mass depth of 3000 meters (Test 4) and accounting for NO_3 and SO_4 emissions from point sources (Test 5). Then area sources were configured as suggested by Scire, including the use of 4 area source groups to account for varying release heights for different source categories (as opposed to one group in Tests 1-5). Finally, Test 6 included use of the Beulah hourly ammonia profile in POSTUTIL.

Results of Test 6, as shown in Tables A-1 and A-2, indicate significantly improved performance with respect to TRSU NO_3, but worse performance for Lostwood NO_3. Results for SO_4 were not significantly affected. This tendency for conflicting results for TRSU and Lostwood NO_3 was also exhibited in Tests 1 through 5, and led the NDDoH to conclude that the Beulah data may not be representative of ammonia background for both TRSU and Lostwood. Moreover, the actual ammonia background affecting Lostwood may be significantly higher than the background affecting TRSU.

In Test 7, the NDDoH found that observational agreement for Lostwood NO_3 can be vastly improved if the ammonia hourly backgound values are approximately doubled (for Lostwood only). All other conditions for Test 7, including the ammonia background for TRSU, remain the same as in Test 6. NO_3 predictions for Test 7 in Tables A-1 and A-2 now show good agreement with observations at both TRSU and Lostwood.

Table A-1
Hybrid CMAQ-CALPUFF Performance Evaluation
Observed and Predicted Concentrations Year 2002 (ug/m^3)

	Observed	Hybrid CMAQ-CALPUFF Predicted*							CMAQ
		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	only
TRSU NO3									
90th Percentile Day	**1.21**	1.50	1.46	1.55	1.43	1.47	1.21	1.21	1.62
Avg 20% Worst Days	**1.42**	1.59	1.59	1.65	1.56	1.59	1.41	1.41	1.84
Annual Average	**0.50**	0.71	0.71	0.73	0.70	0.71	0.53	0.53	0.57
TRSU SO4									
90th Percentile Day	**1.88**	1.72	1.72	1.66	1.77	1.72	1.79	1.79	1.60
Avg 20% Worst Days	**2.43**	1.96	1.97	1.83	1.96	1.98	1.99	1.99	1.76
Annual Average	**1.03**	0.90	0.90	0.86	0.90	0.91	0.91	0.91	0.84
Lostwood NO3									
90th Percentile Day	**1.95**	1.48	1.50	1.56	1.47	1.44	1.13	1.76	2.04
Avg 20% Worst Days	**2.33**	1.55	1.55	1.61	1.52	1.50	1.30	2.03	2.34
Annual Average	**0.79**	0.70	0.70	0.73	0.69	0.67	0.47	0.80	0.79
Lostwood SO4									
90th Percentile Day	**2.22**	2.06	2.03	1.90	2.07	2.19	2.21	2.21	2.43
Avg 20% Worst Days	**2.49**	2.21	2.21	2.09	2.22	2.35	2.36	2.36	2.74
Annual Average	**1.18**	1.07	1.07	1.03	1.08	1.15	1.17	1.17	1.32

* Test 1 - Calpuff run with default BART screening protocol + full emissions inventory + boundary conditions
Test 2 - Calpuff as in Test 1 but using CEMS hrly emissions (SO2, NOX) where available
Test 3 - Calpuff as in Test 1 but using WRAP MM5 12km mesoscale data (in CALMET)
Test 4 - Calpuff as in Test 1 but assuming boundary air mass depth as 3000 m rather than 2000 m
Test 5 - Calpuff as in Test 1 but with addition of NO3 and SO4 emissions from point sources
Test 6 - Calpuff as in Test 1 but assuming boundary air mass depth as 3000 m (Test 4) and with addition of NO3 and SO4 emissions from point sources (Test 5). Area sources configured as 4 groups and Beulah hourly profile used for backgound NH3.
Test 7 - Calpuff as in Test 6 but Beulah hourly NH3 profile doubled for Lostwood

Table A-2
Hybrid CMAQ-CALPUFF Performance Evaluation
Predicted to Observed Ratios 2002

	Hybrid CMAQ-CALPUFF*							CMAQ
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	only
TRSU NO3								
90th Percentile Day	1.24	1.21	1.28	1.18	1.21	1.00	1.00	1.34
Avg 20% Worst Days	1.12	1.12	1.16	1.10	1.12	0.99	0.99	1.30
Annual Average	1.42	1.42	1.46	1.40	1.42	1.06	1.06	1.14
TRSU SO4								
90th Percentile Day	0.91	0.91	0.88	0.94	0.91	0.95	0.95	0.85
Avg 20% Worst Days	0.81	0.81	0.75	0.81	0.81	0.82	0.82	0.72
Annual Average	0.87	0.87	0.83	0.87	0.88	0.88	0.88	0.82
Lostwood NO3								
90th Percentile Day	0.76	0.77	0.80	0.75	0.74	0.58	0.90	1.05
Avg 20% Worst Days	0.67	0.67	0.69	0.65	0.64	0.56	0.87	1.00
Annual Average	0.89	0.89	0.92	0.87	0.85	0.59	1.01	1.00
Lostwood SO4								
90th Percentile Day	0.93	0.91	0.86	0.93	0.99	1.00	1.00	1.09
Avg 20% Worst Days	0.89	0.89	0.84	0.89	0.94	0.95	0.95	1.10
Annual Average	0.91	0.91	0.87	0.92	0.97	0.99	0.99	1.12

* Test 1 - Calpuff run with default BART screening protocol + full emissions inventory + boundary conditions
Test 2 - Calpuff as in Test 1 but using CEMS hrly emissions (SO2, NOX) where available
Test 3 - Calpuff as in Test 1 but using WRAP MM5 12km mesoscale data (in CALMET)
Test 4 - Calpuff as in Test 1 but assuming boundary air mass depth as 3000 m rather than 2000 m
Test 5 - Calpuff as in Test 1 but with addition of NO3 and SO4 emissions from point sources
Test 6 - Calpuff as in Test 1 but assuming boundary air mass depth as 3000 m (Test 4) and with addition of NO3 and SO4 emissions from point sources (Test 5). Area sources configured as 4 groups and Beulah hourly profile used for backgound NH3.
Test 7 - Calpuff as in Test 6 but Beulah hourly NH3 profile doubled for Lostwood